U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-293 637

Comparisons of Models Predicting Ambient Lake Phosphorus Concentrations

(U.S.) Environmental Monitoring and Support Lab, Las Vegas, NV

Feb 79

United States
Environmental Protection
Agency

Environmental Monitoring
and Support Laboratory
P.O. Box 15027
Las Vegas NV 89114

EPA-600/3-79-012
February 1979

PB 293637

Research and Development

EPA

Ecological Research Series

Comparisons of Models Predicting Ambient Lake Phosphorus Concentrations

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environn Protection Agency, have been grouped into nine series. These nine broad gories were established to facilitate further development and application vironmental technology. Elimination of traditional grouping was consci planned to foster technology transfer and a maximum interface in related The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ECOLOGICAL RESEARCH series. This series describes research on the effects of pollution on humans, plant and animal species, and materials. Problems are assessed for their long- and short-term influences. Investigations include formation, transport, and pathway studies to determine the fate of pollutants and their effects. This work provides the technical basis for setting standards to minimize undesirable changes in living organisms in the aquatic, terrestrial, and atmospheric environments.

This document is available to the public through the National Technical Info tion Service, Springfield, Virginia 22161.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/3-79-012	2.
3. RECIPIENT'S ACCESSION NO. PB293637	
4. TITLE AND SUBTITLE COMPARISONS OF MODELS PREDICTING AMBIENT LAKE PHOSPHORUS CONCENTRATIONS	5. REPORT DATE February 1979
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) S.C. Hern, V.W. Lambou, L.R. Williams	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Environmental Monitoring and Support Laboratory Office of Research and Development U.S. Environmental Protection Agency Las Vegas, NV 89114	10. PROGRAM ELEMENT NO. 1BA608
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency-Las Vegas, NV Office of Research and Development Environmental Monitoring and Support Laboratory Las Vegas, NV 89114	13. TYPE OF REPORT AND PERIOD COVERED 03-07-73 to 11-14-73
	14. SPONSORING AGENCY CODE EPA/600/07

15. SUPPLEMENTARY NOTES
Previously released in limited distribution as No. 704 in the Working Paper Series for the National Eutrophication Survey

16. ABSTRACT

The Vollenweider, Dillon, and Larsen/Mercier models for predicting ambient lake phosphorus concentrations and classifying lakes by trophic state are compared in this report. The Dillon and Larsen/Mercier models gave comparable results in ranking 39 lakes relative to known ambient phosphorus concentrations. The Vollenweider model, which does not include a phosphorus retention capacity component, was unable to achieve the high rank correlations found with the other models.

Trophic state predictions from the phosphorus loading models are compared with National Eutrophication Survey lake report designations. Disagreements of 14, 18, and 25 percent, respectively, were found with the Dillon, Larsen/Mercier, and Vollenweider concepts.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Rates Water Quality Mathematical Models	Trophic State Phosphorus Loading	07C

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS (This Report) UNCLASSIFIED	21. NO. OF PAGES 18
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE PC A02/MF A01

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

☆ U.S. GOVERNMENT PRINTING OFFICE: 1979-749-903/12

EPA-600/3-79-012
February 1979

COMPARISONS OF MODELS PREDICTING AMBIENT LAKE PHOSPHORUS CONCENTRATIONS

by

Stephen C. Hern, Victor W. Lambou
and Llewellyn R. Williams
Environmental Monitoring and Support Laboratory
Las Vegas, Nevada 89114

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
ENVIRONMENTAL MONITORING AND SUPPORT LABORATORY
LAS VEGAS, NEVADA 89114

DISCLAIMER

This report has been reviewed by the Environmental Monitoring and Support Laboratory-Las Vegas, U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

Protection of the environment requires effective regulatory actions which are based on sound technical and scientific information. This information must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of specific pollutants in the environment requires a total systems approach which transcends the media of air, water, and land. The Environmental Monitoring and Support Laboratory-Las Vegas contributes to the formation and enhancement of a sound monitoring data base for exposure assessment through programs designed to:

develop and optimize systems and strategies for monitoring pollutants and their impact on the environment

demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs

This report compares models which classify lakes according to their trophic state and predict ambient lake phosphorus concentrations. This report is intended for use by Federal, State and local agencies with responsibility for watershed management as mandated under Sections 305b and 208 of Public Law 92-500. For further information contact the Water and Land Quality Branch, Monitoring Operations Division.

George B. Morgan
Director
Environmental Monitoring and Support Laboratory
Las Vegas

ABSTRACT

The Vollenweider, Dillon, and Larsen/Mercier models for predicting ambient lake phosphorus concentrations and classifying lakes by trophic state are compared in this report. The Dillon and Larsen/Mercier models gave comparable results in ranking 39 lakes relative to known ambient phosphorus concentrations. The Vollenweider model, which does not include a phosphorus retention capacity component, was unable to achieve the high rank correlations found with the other models.

Trophic state predictions from the phosphorus loading models are compared with National Eutrophication Survey lake report designations. Disagreements of 14, 18, and 25 percent, respectively, were found with the Dillon, Larsen/Mercier, and Vollenweider concepts.

INTRODUCTION

The National Eutrophication Survey was initiated in 1972 in response to an Administration commitment to investigate the nationwide threat of accelerated eutrophication to freshwater lakes and reservoirs. The Survey was designed to develop, in conjunction with State environmental agencies, information on nutrient sources, concentrations, and impact on selected freshwater lakes as a basis for formulating comprehensive and coordinated national, regional, and State management practices relating to point source discharge reduction and nonpoint source pollution abatement in lake watersheds.

The Survey collected physical, chemical, and biological data from 815 lakes and reservoirs throughout the contiguous United States. To date, the Survey has yielded more than two million data points. In-depth analyses are being made to advance the rationale and data base for refinement of nutrient water quality criteria for the Nation's freshwater lakes.

COMPARISONS OF MODELS PREDICTING AMBIENT LAKE PHOSPHORUS CONCENTRATIONS

The phosphorus loading-mean depth relationship formulated by Vollenweider (1968) has been widely accepted and used to indicate the degree of eutrophy of lakes and evaluate the level of phosphorus loading to lakes. Dillon (1975) pointed out that there has been too little thought and criticism given to the limitations of the model by people using it. Subsequently, modifications of the basic mass balance equation have been derived to predict mean ambient lake phosphorus concentrations at equilibrium. Dillon (1975) utilizes phosphorus areal loading (L), the retention coefficient for phosphorus (R), the hydraulic flushing rate (P), and mean depth (Z), in a plot of the form

$$\frac{L\ (1-R)}{P}$$

versus Z, to estimate trophic state. Vollenweider (1975) revised his original formula to include T_w, hydraulic residence time, so that areal phosphorus loading (L) is plotted against mean depth (Z) divided by T_w. Larsen and Mercier (1976) provide an alternative (to the prior loading concepts) which avoids the criticism of Edmondson (1970) that the effect of an increasing phosphorus load upon a lake depends, in part, upon whether that increase results from increases in influent flows, concentrations, or both. The Larsen/Mercier formula plots mean tributary phosphorus concentration against phosphorus retention coefficient, called R experimental, computed in the same way as Dillon's R, i.e.,

$$R = 1 - \frac{\text{Total phosphorus leaving}}{\text{Total phosphorus entering}}$$

It is interesting to note that in applying the above-mentioned formula, each of the authors has selected to use levels of 10 and 20 micrograms per liter (µg/l) of ambient lake phosphorus to divide lakes into three standard trophic classifications--oligotrophic, mesotrophic, and eutrophic.

To compare the three models, we selected 39 lakes sampled during 1973 by the National Eutrophication Survey (U.S. Environmental Protection Agency, 1975) which represented the entire range of water transparency as measured by Secchi disk. Table 1 demonstrates the variety of lakes selected.

TABLE 1. THE NUMERICAL AVERAGE AND RANGE OF MEAN CHEMICAL, PHYSICAL AND BIOLOGICAL CHARACTERISTICS OF 39 LAKES, SELECTED FROM THOSE SAMPLED DURING 1973 BY THE NATIONAL EUTROPHICATION SURVEY

PARAMETER	MEAN	RANGE		
Surface Area (km^2)	40.75	0.23	-	263.05
Drainage Area (km^2)	3502.6	4.3	-	38850.0
Mean Depth (m)	7.5	0.9	-	21.0
Maximum Depth (m)	21.6	1.5	-	57.8
Volume ($m^3 \times 10^6$)	379.28	0.45	-	2608.00
Hydraulic Retention Time (Days)	251	1	-	2446
Secchi Disk (cm)	177.8	15.2	-	563.9
Total Phosphorus (µg/liter)	147	5	-	1120
Chlorophyll *a* (µg/liter)	53.9	1.4	-	456.6

The data used in this report are from the various individual National Eutrophication Survey (NES) lake reports for the lakes listed in Table 2, e.g., Report on Lake Lulu (EPA, 1976). Similarly, NES lake reports provide data for Lake Mead (EPA, 1977a) and Flaming Gorge Reservoir (EPA, 1977b), included as examples of the application of the formulas.

Solution analyses based on 20 µg/l were employed to place the three formulas on an equivalent basis by dividing the appropriate theoretical minimum eutrophic "loading" rate for a given lake (i.e., that which would produce an ambient lake concentration of 20 µg/l) into the actual "loading" rate determined for that lake. Hereafter, this ratio will be referred to as the "trophic ratio". Trophic ratios which exceed or equal 1.0 represent eutrophic loadings, whereas trophic ratios extending from 0.5 to less than 1.0 represent mesotrophic loadings and trophic ratios below 0.5 represent oligotrophic loadings, regardless of the formula employed.

Table 2 lists the 39 lakes used in this study, ranked in descending order by total phosphorus concentration, and gives the mean total phosphorus concentration and mean Secchi disk value for each lake. In addition, the trophic states given in the individual NES lake reports are listed along with the trophic ratios calculated for the Larsen/Mercier, Dillon, and Vollenweider models and the trophic states predicted by the ratios. The trophic states indicated in the NES reports were based largely upon lake mean total phosphorus, chlorophyll *a*, Secchi depth, hypolimnetic dissolved oxygen values and phytoplankton data (Allum et al., 1977).

Spearman rank correlation coefficients (rs) were calculated for each trophic ratio against measured mean ambient phosphorus concentrations with the following results: Larsen/Mercier (0.94), Dillion (0.92), and Vollenweider (0.82). The Larsen/Mercier model provided the best estimation of the relative rank of the lakes based on ambient phosphorus concentrations. It was followed closely by the Dillon model. Both of these models take into consideration the phosphorus retention capacity of lakes. These models are

TABLE 2. COMPARISON OF LAKE AMBIENT PHOSPHORUS PREDICTION MODELS AND TROPHIC CLASSIFICATIONS WITH ACTUAL AMBIENT LAKE CONDITIONS. THE 39 LAKES COMPARED ARE RANKED IN DESCENDING ORDER BY MEAN SUMMER AMBIENT PHOSPHORUS CONCENTRATION

RANK	LAKE NAME (STATE)	MEAN AMBIENT TOTAL-P (µg/l)	MEAN AMBIENT SECCHI DEPTH (cm)	NES TROPHIC STATE*	LARSEN/MERCIER		DILLON		VOLLENWEIDER	
					TROPHIC RATIO	TROPHIC STATE*	TROPHIC RATIO	TROPHIC STATE*	TROPHIC RATIO	TROPHIC STATE*
1	Lake Lulu (Fla.)	1120	23	E	259.90 - E		Δ		75.62 - E	
2	Slocum Lake (Ill.)	882	20	E	61.77 - E		74.00 - E		29.42 - E	
3	Lake Hancock (Fla.)	608	30	E	79.90 - E		Δ		Δ	
4	Alligator Lake (Fla.)	429	58	E	38.92 - E		Δ		Δ	
5	Fox Lake (Ill.)	322	23	E	10.81 - E		3.40 - E		12.66 - E	
6	Highland (Silver) Lake (Ill.)	258	20	E	14.61 - E		15.38 - E		5.43 - E	
7	Horseshoe Lake (Ill.)	256	25	E	11.81 - E		12.00 - E		1.96 - E	
8	Killen Pond (Del.)	216	66	E	5.58 - E		5.67 - E		9.25 - E	
9	Lake Loramie (Ohio)	204	15	E	18.57 - E		18.67 - E		5.02 - E	
10	Crab Orchard Lake (Ill.)	184	58	E	7.40 - E		7.33 - E		7.42 - E	
11	Duhernal Lake (N.J.)	179	61	E	3.17 - E		3.33 - E		18.92 - E	

* E = eutrophic, M = mesotrophic, O = oligotrophic and Δ = insufficient data to make estimate of trophic ratio.

(Continued)

TABLE 2. COMPARISON OF LAKE AMBIENT PHOSPHORUS PREDICTION MODELS AND TROPHIC CLASSIFICATIONS WITH ACTUAL AMBIENT LAKE CONDITIONS. THE 39 LAKES COMPARED ARE RANKED IN DESCENDING ORDER BY MEAN SUMMER AMBIENT PHOSPHORUS CONCENTRATION (Continued)

RANK	LAKE NAME (STATE)	MEAN AMBIENT TOTAL-P (µg/l)	MEAN AMBIENT SECCHI DEPTH (cm)	NES TROPHIC STATE*	LARSEN/MERCIER		DILLON		VOLLENWEIDER	
					TROPHIC RATIO	TROPHIC STATE*	TROPHIC RATIO	TROPHIC STATE*	TROPHIC RATIO	TROPHIC STATE*
12	Lake Charleston (Ill.)	164	23	E	8.57 - E		7.50 - E		15.91 - E	
13	Lake Apopka (Fla.)	161	29	E	19.17 - E		22.00 - E		3.94 - E	
14	Marsh Lake (Ind.)	115	127	E	5.80 - E		5.92 - E		4.54 - E	
15	Saluda Lake (S.C.)	73	68	M	1.84 - E		1.88 - E		5.07 - E	
16	Arkabutla Reservoir (Miss.)	58	64	E	11.28 - E		11.39 - E		2.58 - E	
17	Barren River Reservoir (Ky.)	49	123	E	3.35 - E		2.32 - E		2.10 - E	
18	Lake Chesdin (Va.)	40	120	E	2.20 - E		2.21 - E		2.24 - E	
19	Lay Lake (Ala.)	39	104	E	4.84 - E		4.20 - E		5.72 - E	
20	Cherokee Lake (Tenn.)	37	141	E	2.28 - E		2.43 - E		3.61 - E	
21	Hickory Lake (N.C.)	34	114	E	2.04 - E		1.74 - E		3.13 - E	
22	Walter F. George Reservoir (Ga.)	30	110	E	3.12 - E		3.25 - E		3.44 - E	

* E = eutrophic, M = mesotrophic, O = oligotrophic and Δ = insufficient data to make estimate of trophic ratio.

(Continued)

TABLE 2. COMPARISON OF LAKE AMBIENT PHOSPHORUS PREDICTION MODELS AND TROPHIC CLASSIFICATIONS WITH ACTUAL AMBIENT LAKE CONDITIONS. THE 39 LAKES COMPARED ARE RANKED IN DESCENDING ORDER BY MEAN SUMMER AMBIENT PHOSPHORUS CONCENTRATION (Continued)

RANK	LAKE NAME (STATE)	MEAN AMBIENT TOTAL-P (µg/l)	MEAN AMBIENT SECCHI DEPTH (cm)	NES TROPHIC STATE*	LARSEN/MERCIER		DILLON		VOLLENWEIDER	
					TROPHIC RATIO	TROPHIC STATE*	TROPHIC RATIO	TROPHIC STATE*	TROPHIC RATIO	TROPHIC STATE*
23	Moultrie Lake (S.C.)	25	134	E	1.51 - E		1.55 - E		1.70 - E	
24	Lake Hopatcong (N.J.)	25	231	E	1.32 - E		1.00 - E		0.34 - O	
25	Tims Ford Reservoir (Tenn.)	25	240	E	2.22 - E		2.70 - E		1.11 - E	
26	Lake Minnehaha (Fla.)	22	140	E	2.11 - E		Δ		Δ	
27	Murray Lake (S.C.)	20	218	E	1.56 - E		1.56 - E		1.49 - E	
28	Chatuge Lake (Ga.)	17	310	M	1.06 - E		1.10 - E		0.56 - M	
29	Liberty Reservoir (Md.)	15	381	M	0.71 - M		0.76 - M		1.80 - E	
30	Wanaque Reservoir (N.J.)	14	467	M	1.31 - E		0.96 - M		0.48 - O	
31	Maxinkuckee Lake (Ind.)	14	221	M	1.20 - E		1.33 - E		0.75 - M	
32	Dale Hollow Reservoir (Ky.)	13	318	M	0.49 - O		0.47 - O		0.49 - O	

* E = eutrophic, M = mesotrophic, O = oligotrophic and Δ = insufficient data to make estimate of trophic ratio.

(Continued)

TABLE 2. COMPARISON OF LAKE AMBIENT PHOSPHORUS PREDICTION MODELS AND TROPHIC CLASSIFICATIONS WITH ACTUAL AMBIENT LAKE CONDITIONS. THE 39 LAKES COMPARED ARE RANKED IN DESCENDING ORDER BY MEAN SUMMER AMBIENT PHOSPHORUS CONCENTRATION (Continued)

RANK	LAKE NAME (STATE)	MEAN AMBIENT TOTAL-P (µg/l)	MEAN AMBIENT SECCHI DEPTH (cm)	NES TROPHIC STATE*	LARSEN/MERCIER		DILLON		VOLLENWEIDER	
					TROPHIC RATIO	TROPHIC STATE*	TROPHIC RATIO	TROPHIC STATE*	TROPHIC RATIO	TROPHIC STATE*
33	Lake Wallenpaupack (Penn.)	13	434	M	1.10 -	E	1.12 -	E	0.50 -	M
34	Martin Lake (Ala.)	13	230	M	1.04 -	E	0.96 -	M	1.35 -	E
35	John W. Flannagan Reservoir (Va.)	11	366	M	0.66 -	M	0.69 -	M	1.92 -	E
36	Deep Creek Lake (Md.)	11	366	M	0.39 -	O	0.38 -	O	0.34 -	O
37	Summersville (W.Va.)	10	549	M	0.83 -	M	0.83 -	M	1.28 -	E
38	Harveys Lake (Penn.)	9	564	M	0.55 -	M	0.59 -	M	0.54 -	M
39	Tygart Reservoir (W.Va.)	5	320	M	0.95 -	M	0.94 -	M	2.02 -	E

* E = eutrophic, M = mesotrophic, O = oligotrophic and Δ = insufficient data to make estimate of trophic ratio.

very similar, as areal phosphorus loading (L) divided by mean depth (Z) approximates mean tributary concentration. The major difference between the models is the flushing rate (P) employed by Dillon.

The Vollenweider model, which does not contain a phosphorus retention capacity element, produced the poorest estimate of the ambient phosphorus concentration.

Comparison of the NES trophic state assignment to the various phosphorus model predictions revealed a 14, 18, and 25 percent disagreement, respectively, for the Dillon, Larsen/Mercier, and Vollenweider concepts. The Dillon and Larsen/Mercier models predicted the same trophic state in 33 of 35 lakes. The only exceptions were in Martin Lake and Wanaque Reservoir where the trophic ratios, although very close, lay on opposite sides of the somewhat arbitrary borderline. Nine of the 35 Vollenweider trophic state predictions differed from the Dillon model predictions, while 8 differed from the Larsen/Mercier model estimates. Generally, the Dillon and Larsen/Mercier models not only predicted the same trophic state but their respective trophic ratios were mathematically quite consistent. By comparison, the Vollenweider model provided less consistent trophic state results and greater variation in trophic ratios.

Wanaque Reservoir was classified as eutrophic, mesotrophic, and oligotrophic by the three concepts. However, the Dillon and Larsen/Mercier trophic ratios were actually very close (0.96 and 1.13, respectively).

Even though all of the models produced relatively high Spearman rank correlation coefficients, these models must be used with caution as the comparisons given in Table 3 illustrate. For the two western reservoirs, the Vollenweider model predicted a much higher eutrophic loading rate than the other models. Both of these reservoirs have high phosphorus retention capacities (associated with high suspended sediment deposition)--Lake Mead (0.93), and Flaming Gorge Reservoir (0.82). These examples reinforce the concept that the Dillon and the Larsen/Mercier models give comparable results. However, the Larsen/Mercier model requires less information [(P) flushing rate and (Z) mean depth are not required] and produced the highest Spearman rank correlation coefficient (rs). Also, the Dillon model required mean depth information which is neither uniformly available nor necessarily accurate, without an extensive bathymetric survey. The mean depth of the lake is the only independent variable which sets the level of the theoretical eutrophic "loading" rate in the Dillon model. In the Larsen/Mercier model the independent variable which controls the theoretical eutrophic loading rate is the phosphorus retention capacity.

TABLE 3. COMPARISON OF THREE MODELS TO PREDICT MEAN AMBIENT LAKE PHOSPHORUS CONCENTRATIONS AT EQUILIBRIUM IN TWO RESERVOIRS

	CALCULATED MODEL VALUE	TROPHIC STATE LEVELS		TROPHIC RATIO	PREDICTED TROPHIC STATE
		EUTROPHIC	OLIGOTROPHIC		
Lake Mead, Nev./Ariz.					
Vollenweider	6.23 $g/m^2/yr$	0.78 $g/m^2/yr$	0.39 $g/m^2/yr$	7.98	Eutrophic
Larsen/Mercier	372 µg/l	298.5 µg/l	149.5 µg/l	1.29	Eutrophic
Dillon	1.47 g/m^2	1.18 g/m^2	0.59 g/m^2	1.24	Eutrophic
Flaming Gorge, Wyo./Utah					
Vollenweider	1.35 $g/m^2/yr$	0.76 $g/m^2/yr$	0.38 $g/m^2/yr$	1.77	Eutrophic
Larsen/Mercier	93.5 µg/l	152.6 µg/l	76.9 µg/l	0.60	Mesotrophic
Dillon	0.41 g/m^2	0.68 g/m^2	0.34 g/m^2	0.60	Mesotrophic

LITERATURE CITED

Allum, M.O., R.E. Glessner, and J.H. Gakstatter. 1977. An evaluation of the National Eutrophication Survey data. Working Paper No. 900. Assessment and Criteria Development Division, Corvallis Environmental Research Laboratory, Corvallis, Oregon. 75 p.

Dillon, P.J. 1975. The phosphorus budget of Cameron Lake, Ontario: The importance of flushing rate to the degree of eutrophy of lakes. Limnol. Oceanogr. 20:28-39.

Edmondson, W.T. 1970. Book review (Water management research). Limnol. Oceanogr. 15:169-170.

Larsen, D.P. and H.T. Mercier. 1976. Phosphorus retention capacity of lakes. J. Fish. Res. Board Can. 33:1742-1750.

U.S. Environmental Protection Agency. 1975. National Eutrophication Survey Methods 1973 - 1976. Working Paper No. 175. Environmental Monitoring and Support Laboratory, Las Vegas, Nevada, and Corvallis Environmental Research Laboratory, Corvallis, Oregon. 91 p.

U.S. Environmental Protection Agency. 1976. Report on Lake Lulu, Florida. Working Paper No. 263. Environmental Monitoring and Support Laboratory, Las Vegas, Nevada, and Corvallis Environmental Research Laboratory, Corvallis, Oregon. 30 p.

U.S. Environmental Protection Agency. 1977a. Report on Lake Mead, Nevada and Arizona. Working Paper No. 808. Environmental Monitoring and Support Laboratory. Las Vegas, Nevada, and Corvallis Environmental Research Laboratory, Corvallis, Oregon. 91 p.

U.S. Environmental Protection Agency. 1977b. Report on Flaming Gorge Reservoir, Utah and Wyoming. Working Paper No. 885. Environmental Monitoring and Support Laboratory. Las Vegas, Nevada, and Corvallis Environmental Research Laboratory, Corvallis, Oregon. 67 p.

Vollenweider, R.A. 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Organ. Econ. Coop. Dev., Paris. Tech. Rep. DAS/CSI/68.27:159 p.

Vollenweider, R.A. 1975. Input - output models with special reference to phosphorus loading concept in limnology. Schweiz. Z. Hydrol. 37:53-83.